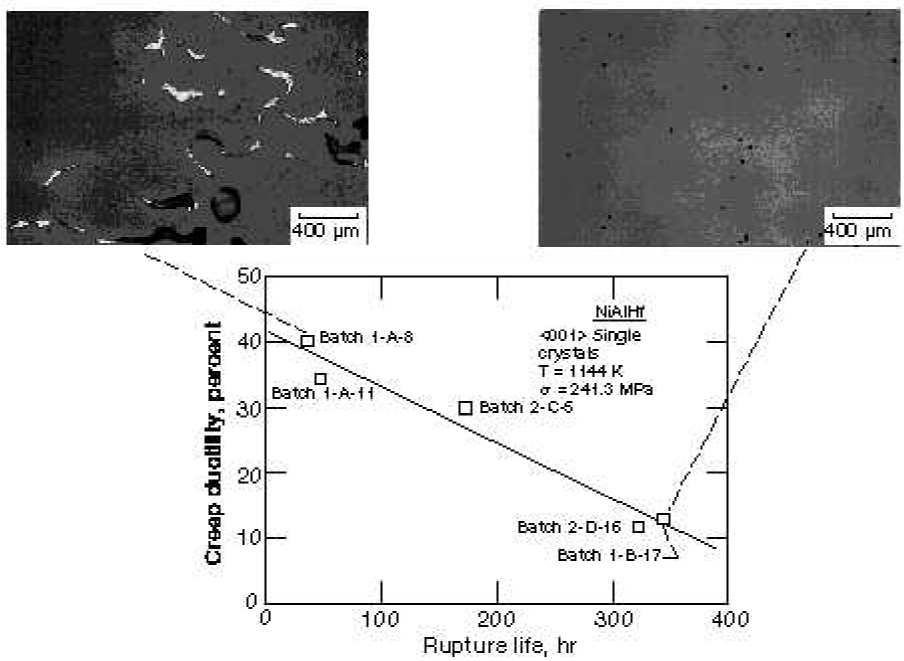
Source of Scatter in the Creep Lives of NiAl(Hf) Single Crystals Revealed

In recent years, there has been an increased emphasis in developing NiAl-based alloys for high- temperature applications in aircraft engines (ref. 1). In comparison to commercial superalloys, binary NiAl has a higher melting temperature, lower density, larger thermal conductivity, and better oxidation resistance. These properties make it a desirable material to replace superalloys as blades and vanes in aircraft engines. Despite this attractive combination of properties, binary NiAl cannot be used as a reliable structural material because of its low-temperature brittleness and poor high-temperature creep strength.

GE Aircraft Engines in Cincinnati, Ohio, has recently developed NiAl(Hf) alloys that have creep strengths comparable to commercial superalloys while maintaining the other desirable properties of binary NiAl. The microstructures of these alloys consist of finely distributed G-phase ($Ni_{16}Hf_6Si_7$) precipitates, which strengthen the NiAl matrix. However, while the creep properties of these alloys were being evaluated, considerable scatter was observed in the creep lives of specimens tested under identical stress and temperature conditions. Although these alloys had nominally the same composition, the test specimens were obtained from four different ingots (A, B, C, and D) that had been heat treated under similar conditions. The NASA Lewis Research Center began the present study at the request of GE Aircraft Engines under a Space Act Agreement to identify the source of this scatter.

Detailed fracture and microstructural analyses of the failed specimens and the original ingots were conducted in this study. The fracture analysis revealed that, except in one instance, the failure could not be traced to any extrinsic defects, such as shrinkage porosity, machining cracks, or large particles. Instead, an analysis of the creep data revealed an inverse linear correlation between the creep ductility and creep life (see figure), thereby suggesting that the source of the scatter was somehow related to factors affecting the deformation behavior of the material rather than any random occurrence. In addition, the geometry of the fracture surfaces of the specimens with shorter creep lives were more elliptical than those with longer creep lives. This observation suggested that specimens with shorter creep lives had deformed by single slip, whereas those with longer lives had deformed by normal multiple slip. Evidence for the latter slip morphology was confirmed by scanning electron microscopy. Another important clue was provided by the creep data, which revealed that the two specimens with the shortest lives had been machined from the same ingot. Therefore, it became clear that the scatter in the creep lives resulted from differences in the microstructure probably due to differences in melting and heat-treatment practices.

Transmission electron microscopy revealed that specimens with short creep lives contained large amounts of undissolved Hf-rich particles segregated in the interdendritic regions. In contrast, the densities of these particles were much smaller in specimens with longer creep lives. The presence of these Hf-rich particles appeared to influence the creep behavior of these alloys in two ways. First, the particles depleted the surrounding matrix of Hf, and possibly Si, which in turn resulted in a lower density of the strengthening G-phase precipitates in comparison to the portions of the matrix that were far away from the particles. Second, the large particles appeared to significantly bias the stress fields around them, which in extreme cases resulted in a deviation from multiple slip behavior to single slip behavior. Therefore, we concluded that the scatter in the creep lives was due to improper heat-treatment conditions that left undissolved Hf-rich particles in some of the ingots. In response to these findings, GE Aircraft Engines is modifying their heat treatment and processing schedules to reduce scatter in the creep lives of these alloys to within acceptable limits.



Scatter in the creep rupture lives and creep ductility between four batches of a NiAl(Hf) alloy after deformation at 1145 K under an initial stress of 241.3 MPa.